Journal of Plant Nutrition
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713597277

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Online Publication Date: 01 October 2007
To cite this Article: Rego, Thomas J., Sahrawat, Kanwar L., Wani, Suhas P. and Pardhasaradhi, Gazula (2007) 'Widespread Deficiencies of Sulfur, Boron, and Zinc in Indian Semi-Arid Tropical Soils: On-Farm Crop Responses', Journal of Plant Nutrition, 30:10, 1569 - 1583
To link to this article: DOI: 10.1080/01904160701615475
URL: http://dx.doi.org/10.1080/01904160701615475

Journal of Plant Nutrition, 30: 1569–1583, 2007

ISSN: 0190-4167 print / 1532-4087 online
DOI: 10.1080/01904160701615475

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ABSTRACT

On-farm studies were conducted during 2002–2004 to determine fertility status, including sulfur (S) and micronutrients, and crop response to fertilization on farmers' fields in the semi-arid zone of India. Nine hundred-twenty four soil samples taken from farmers' fields, spread in the three districts of Andhra Pradesh (India), were analyzed for soil chemical fertility parameters. Results showed that samples were low in organic carbon (C), total nitrogen (N), and low to moderate in extractable phosphorus (P), but adequate in available potassium (K). Analyses of soil samples for extractable S and micronutrients was most revealing and showed that 73–95% of the farmers' fields were deficient in S, 70–100% in boron (B), and 62–94% in zinc (Zn). On-farm trials conducted during three seasons (2002–2004) showed significant yield responses of maize, castor, groundnut, and mung bean to the applications of S, B, and Zn. The yield responses were larger when S, Zn, and B were applied along with N and P. Applications of S, B and Zn also significantly increased the uptake of N, P, K, S, B, and Zn in the crop biomass. Results show widespread deficiencies of S, B, and Zn under dryland agricultural conditions; results also show that the nutrient deficiencies can be diagnosed by soil testing. It was concluded that the drylands in the semi-arid regions of India were not only thirsty (water shortage), but also hungry (nutrient deficiencies).

Keywords: Crop productivity, soil testing, macro and micronutrient deficiencies, sulfur, boron, zinc, rainfed agriculture, plant nutrition, nutrient uptake, water shortage

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Received 10 April 2006; accepted 5 October 2006.
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INTRODUCTION

Globally, sulfur (S) and micronutrient deficiencies have been reported with increasing frequency, especially from intensive, irrigated agricultural production systems; and Indian agriculture is no exception (Kanwar, 1972; Takkar et al., 1989; Pasricha and Fox, 1993; Scherer, 2001; Fageria et al., 2002; Katyal and Rattan, 2003). In India, micronutrient deficiencies have been reported as one of the main causes for yield plateau or even yield decline, especially in irrigated intensified systems (Takkar et al., 1989). For example in the irrigated, fertile Indo-Gangetic plains, the deficiencies of secondary nutrients such as S and micronutrients, especially zinc (Zn), are known as constraints to crop production and productivity (Takkar, 1996; Katyal and Rattan, 2003).

While soil and plant testing for diagnostic purposes have been more frequently employed in intensive, irrigated systems, and micronutrient deficiencies have been reported with increasing frequencies (Takkar, 1996), little attention, however, has been paid to diagnose the deficiencies of S and micronutrients in the field under dryland farming in the semi-arid tropical (SAT) regions of India. In general, soils in the Indian semi-arid tropics are marginal compared to irrigated soils; and at relatively low levels of productivity, the deficiencies of major nutrients, especially nitrogen (N) and phosphorus (P) are considered important for the SAT soils (El-Swaify et al., 1985) and hence little research effort has been devoted to determine the role of secondary nutrients such as S and micronutrients in crop production and productivity.

It is well recognized that the productivity of SAT soils is low due to water shortage. However apart from water shortages, low soil fertility also constrains crop productivity in the SAT regions of India (Rego et al., 2003). Moreover, the use of mineral fertilizers (mostly N and P) is very low in rainfed production systems and most of the fertilizer use is confined to irrigated production systems (Jha and Sarin, 1984; Katyal, 2001). In rainfed systems, the deficiencies of N and P are considered important (El-Swaify et al., 1985). Due to low crop productivity in the drylands, it is assumed that mining of micronutrients is much less than in irrigated systems. Rego et al. (2003) conducted a study to determine major nutrient balances on 98 farmers' fields (Alfisols) in sorghum- and groundnut-based cropping systems in the Indian semi-arid tropics. The balances were negative for N and potassium (K) in majority of farm lands. The negative balances of N and K were observed mainly due to low rates of applications of these nutrients via mineral or organic sources. However, the supply of P in the soil was maintained at a threshold level through addition of P. This research was confined only to major nutrients and the balances of secondary and micronutrients were not studied.

In the SAT regions, best results in terms of productivity increase and sustainability are achieved when holistic approach for the soil and water conservation measures are implemented along with nutrient management, and choice of crops and their management options (Wani et al., 2003). It is also observed that in assured rainfall areas in the SAT regions (with annual rainfall 750 mm or above), response of crops to N and P are assured, although the extent of crop response to these nutrients vary with the seasonal rainfall and its distribution (El-Swaify et al., 1985; Wani et al., 2003). The on-going farmer-participatory integrated watershed management program at ICRISAT provided the opportunity to implement nutrient management along with soil and water conservation practices in farmers' fields in the Indian semi-arid tropics.

During on-farm survey in the 1999 cropping season, soil samples taken from one of the ICRISAT watersheds, Mili watershed in Lalatora village in Vidisha district of Madhya Pradesh (India), were low in extractable S and selected micronutrients, especially boron (B) and Zn. Follow-up study on the application of B and Zn nutrients significantly increased soybean yields during the rainy season. Taking leads from this preliminary observation, systematic and detailed analysis of soil samples taken from farmers' fields in various ICRISAT watersheds in India was conducted. This paper presents the results of experiments conducted during 2002–2004 in farmers' fields that show widespread deficiency of S, B, and Zn in three districts of Andhra Pradesh, as revealed by soil analysis and on-farm responses of field crops to the applications of these plant nutrients.

MATERIALS AND METHODS

On-Farm Sites

Under the integrated watershed management project, experiments were conducted during 2002–2004 under rainfed conditions in farmers' fields in Mahabubnagar, Nalgonda, and Kurnool districts of Andhra Pradesh state, India.

These three districts are the most drought-prone districts in Andhra Pradesh; and are located in the hot moist semi-arid agro-ecological sub-region of the state. These three districts represent the typical rainfed conditions of the Deccan Plateau in South India and are characterized by hot summers and relatively very mild winters. The experimental sites receive low and erratic annual rainfall. Thus the cropping is prevalent during the south-west monsoon season (June through October), which on average receive 450 to 540 mm rainfall.

The soils at the sites are Alfisols, light in texture and low in general fertility, especially organic carbon (C) and nitrogen (N). The inputs of plant nutrients through external sources and organic matter additions are very low, and this is the cause of low fertility and low organic status of soils. The soils have low to medium water holding capacity (100–150 mm) depending on the depth of the soil profile.

In the first year (2002 cropping season, June–October), on-farm trials in nine nucleus watersheds were conducted. These nine nucleus watersheds were located in Kurnool, Mahabubnagar, and Nalgonda districts of Andhra Pradesh;

each district had three watersheds. During the second (2003) and third (2004) cropping seasons, work was extended to 50 watersheds in the same three districts. One more nucleus watersheds were added; and thus there were 10 nucleus watersheds in the three districts in 2003 and 2004. Each nucleus watershed had four satellite watersheds, surrounding the nucleus watershed.

Soil Sampling and Soil Analysis

The number of farmers cultivating arable land varied across the watersheds. Each watershed was about 500 ha in area; and the number of farmers in a watershed varied from 160 to 180. The farm holding size within a watershed also varied (from about 0.5 to > 5 ha). For efficient, cost effective, and representative soil sampling strategy a stratified random sampling along the toposequence was developed.

As a first step, a rapid rural appraisal was conducted and divided the various watersheds into three groups based on the position of the fields on a toposequence: top, middle, and bottom, depending on the elevation and drainage pattern. Different soil types were separated in each category. The farmers were grouped into large, medium, and small holders in each watershed based on farmers' information. In all the watersheds, small farmers had <2.0 ha, medium farmers had between 2 and 5 ha, and large farmers had > 5 ha land. Twenty percent of the farmers' fields were randomly selected in each position on the toposequence proportional to the farm size.

In each selected farmer's field, a major crop in the field was selected for a trial and 8 to 10 cores of surface (0–15 cm depth) soil samples were collected. The soil samples were processed– air-dried and powdered with wooden hammer to pass through a 2-mm sieve. For organic C and total N analyses, the soil samples were finely powdered to pass through a 0.25-mm sieve.

Prepared soil samples were analyzed in the ICRISAT Analytical Services Laboratory. Soil pH was measured by a glass electrode using a soil to water ratio of 1:2; electrical conductivity (EC) was determined by an EC meter using a soil to water ratio of 1:2. Organic C was determined using the Walkley-Black method (Nelson and Sommers, 1996) and total N as described by Dalal et al. (1984). Exchangeable K was determined using the ammonium acetate method (Helmke and Sparks, 1996). Available S was measured using 0.15% calcium chloride ($CaCl_2$) as an extractant (Tabatabai, 1996); available P was measured using the sodium bicarbonate ($NaHCO_3$) test (Olsen and Sommers, 1982). Available Zn was extracted by diethylene triaminepentaacetic acid (DTPA) reagent (Lindsay and Norvell, 1978) and available B was extracted by hot water (Keren, 1996).

On-Farm Trials

During 2002–2004 cropping seasons (June-September), a number of trials in three districts using mung bean (*Vigna rediata*), maize (*Zea mays*), groundnut

(*Arachis hypogaea*), and castor (*Ricinus communis*) as test crops were conducted; they are the important crops grown in the region. The number of trials with maize was 20 in 2002, 24 in 2003, and 19 in 2004 season. For castor, the trials were 8 in 2002, 17 in 2003, and 6 in the 2004 season. The trials with groundnut were 19 in 2002, 30 in 2003, and 40 in the 2004 season; for mung bean, there were 9 trials in 2002, 6 in 2003, and 12 in the 2004 season. Each farmer for a crop was treated as a replication.

In the first year (2002) farmers' participatory meetings were conducted in all the nine watersheds in three districts. The results of soil analyses were discussed with respective farmers in group meetings and fifteen volunteer farmers from each watershed were identified for conducting on-farm trials.

In the first year trials, the two treatments consisted of: (i) control or farmers' nutrient inputs (termed FI), and (ii) FI + SBZn (30 kg S plus 0.5 kg B and 10 kg Zn ha^{-1}).

These treatments were imposed on 2000 m^2 plots, side by side. Farmers' crops and variety, and crop management practices were the same in both the treatments.

In the 2003 cropping season, activities were extended to 50 (10 nucleus plus 40 satellite watersheds) watersheds. The same procedure of soil sampling, analyses, and meeting with farmer groups to discuss analytical results and selecting volunteer farmers in the new watersheds was followed. During the 2003 and 2004 seasons, one additional treatment was added consisting of SBZn plus N + P. As in previous year, each farmer field was considered as one replication. In the 2003 and 2004 trials, the treatments were applied to plots of 1000 m^2 area, arranged side by side on the same piece of land.

For applying nutrients as per SBZn treatment, S, B, and Zn was applied via a mixture, which consisted of 200 kg gypsum (30 kg S ha^{-1}), 5 kg borax (0.5 kg B ha^{-1}) and 50 kg zinc sulfate (10 kg Zn ha^{-1}) ha^{-1}; the mixture was surface broadcast on the plot before the final land preparation. The SBZn + NP treatment consisted of the same amount of S, B, and Zn as in SBZn plus 60 kg N for maize and castor or 20 kg N ha^{-1} for groundnut and mung bean; and P was added at 30 kg P_20_5 ha^{-1}. The treatment SBZn was applied along with P plus 20 kg N ha^{-1} as basal to all crops and 40 kg N ha^{-1} was top dressed in the case of maize and castor. In the case of NP treatment, 20 kg N and 30 kg P_20_5 ha^{-1} was applied to all crops as basal and 40 kg N ha^{-1} as topdressing for maize and castor. Similarly, other nutrient treatments including FI + SBZn, FI + SBZn + NP were imposed as described earlier.

Harvest of Crops for Yield and Plant Analysis

At the time of harvest of the crops, plant samples were collected from three spots in each treatment. From each spot, an area of about 4 m^2 was harvested. Economic parts of the plants were separated from vegetative parts. Grain and stover or straw or haulm weights were taken and brought to the ICRISAT Center in Patancheru (India). The plant samples were dried at 60°C for 48 h and dry weights of grain and straw samples computed.

Sub-samples of grain and straw/stover/haulm were dried at 60°C, ground, and analyzed for total N, P, K, S, Zn, and B in the ICRISAT Analytical Services Laboratory. Total N, P, and K in plant materials were determined by digesting the samples with sulfuric acid-selenium. Nitrogen and P in the digests were analyzed using autoanalyzer, and K in digests was analyzed using atomic absorption spectrophotometer (Sahrawat et al., 2002a). Zinc in plant samples was determined by digesting them with triacid; and Zn in digests was analyzed using atomic absorption spectrophotometer (Sahrawat et al., 2002b). Total S and B in plant samples were determined by ICP-AES in digests prepared by digesting the samples with nitric acid (Mills and Jones, 1996).

Statistical Analysis of the Data

Crop yield obtained were converted to kg ha^{-1} and tabulated according to the crop and treatments. Total nutrient uptake in the biomass was computed from the data on grain and straw yield and nutrient concentration in the grain and straw samples. The data was subjected to statistical analysis using the Genstat 7th edition package.

RESULTS AND DISCUSSION

Fertility Status of Farmers' Fields

A summary of the chemical analysis of soil samples taken from farmers' fields in the three districts of Andhra Pradesh (India) during 2002–2004 showed that the fields had a wide range in pH, were low in organic C and total N, low to moderate in Olsen-P and generally adequate in exchangeable K. However, the most revealing results on soil chemical analysis are the levels of extractable S, B, and Zn in the samples (Table 1). The tentative critical limits in the soil, used for separating deficient fields from non-deficient for available S, B, and Zn are: 8-10 mg kg^{-1}soil $CaCl_2$ extractable S, 0.58 mg kg^{-1}soil hot water extractable B, and 0.75 mg kg^{-1}soil DTPA extractable Zn in the soil. Soil samples lower than the critical limits are characterized as deficient in a particular nutrient (Sahrawat, 2002).

In the watersheds of Nalgonda district, soil samples from 99% of farmers' fields were deficient in available B, 94% of the farmers' fields were deficient in available Zn, and 89% of farmers' fields were deficient in available S. In Mahabubnagar district watersheds, soil samples from 98%, 83%, and 89% farmers' fields were respectively deficient in available B, Zn, and S. Similarly

Table 1
Chemical characteristics of 924 soil samples collected from farmers' fields in three districts of Andhra Pradesh, India, 2002–04

District	No of Fields		pH	Organic C g kg^{-1}	Total N	Olsen -P mg kg^{-1}	Exch.K	Extractable nutrient elements (mg kg^{-1}) S	B	Zn
Nalgonda	256	Range	5.7–9.2	1.2 – 13.6	144-947	0.7–37.6	34–784	1.4–93.0	0.02–1.48	0.08–16.00
		Mean	7.7	4.0	410	8.5	135	7.00	0.26	0.73
		% deficient[a]						86	93	73
Mahabubnagar	359	Range	5.5–9.1	0.8 – 12.0	123–783	0.7–61.0	25–487	1.1–44.0	0.02–1.62	0.12–35.60
		Mean	7.1	3.6	342	9.1	117	11.5	0.22	1.34
		% deficient						73	94	62
Kurnool	309	Range	5.6–9.7	0.9 – 10.6	26–966	0.4–36.4	33–508	1.3–68.2	0.04–1.64	0.08–4.92
		Mean	7.8	3.4	295	7.9	142	5.6	0.34	0.42
		% deficient						88	83	94

[a]The critical limits in the soil used : 8–10 mg kg^{-1} for calcium chloride extractable S; 0.58 mg kg^{-1} for hot water extractable B; 0.75 mg kg^{-1} for DTPA extractable Zn.

in the Kurnool district, 92% farmers' fields were deficient in available B, 81% in available Zn, and 88% in available S (Table 1).

Results on analysis of soil samples for chemical fertility parameters indicate a wide spread deficiency of S, B, and Zn in farmers' fields in the semi-arid region of India. These results further suggest that the S, B, and Zn reserves in the drylands are exhausted due to continuous cropping without application of these plant nutrients. The extent of deficiency of S, B, and Zn, as revealed by soil testing, are comparable to those reported from well endowed and intensive, irrigated production systems (Takkar et al.,1989; Takkar, 1996). The low levels of soil organic C and N is not entirely surprising as the production systems are based on little or no inputs of organic matter to the soils (El-Swaify et al., 1985; Rego et al., 2003).

Response of Crops to Applied Nutrients

Maize

Compared to the FI treatment, the applications of FI + SBZn and FI + SBZn + NP nutrient treatments significantly increased grain yield and total biomass of maize during the seasons of experimentation (Table 2).

In the 2002 season, SBZn treatment on average yielded 67% more grain and 24% more stover than the FI treatment. Similar significant yield ($P < 0.05$) responses were obtained in the 2003 (48 and 37% increase in grain and stover, respectively) and 2004 (28 and 16% increase in grain and stover, respectively) cropping seasons. In the 2003 and 2004 seasons, the addition of N and P along with SBZn resulted in 75 and 74% more grain yield and 53 and 55% more stover yield, respectively. From the results of trials conducted in the 2004 season, the SBZn treatment gave 680 kg ha^{-1} more grain yield compared to FI treatment. Similarly, 540 kg ha^{-1} extra stover yield was obtained by the application of SBZn over the FI treatment.

As in the case of grain and total biomass yields, the application of nutrient treatments SBZn and SBZn + NP over the FI treatment significantly increased the uptake of N, P, K, S, B, and Zn in the maize crop biomass (Table 2). For example in the 2002 season, FI + SBZn significantly ($p < 0.05$) increased the total uptake of major nutrients, and S, B and Zn in the maize crop biomass. Similarly in the 2003 season, the application of SBZn and SBZn + NP over the FI treatment significantly increased the uptake of N, P, K, S, B, and Zn as compared to the FI treatment. The highest uptakes of nutrients, compared to the FI treatment, were obtained when SBZn and NP were applied together; and the differences in total nutrient uptake between FI + SBZn and FI + SBZn + NP were also significant. In the 2004 season, the application of nutrient combinations increased total uptake of nutrients as compared to the FI treatment, and the highest uptake of nutrients by the crop biomass was obtained with the FI + SBZn + NP treatment (Table 2).

Table 2
Yield and nutrient uptake of maize and castor in response to fertilization in Andhra Pradesh, India, 2002–2004

Treatment	Grain yield kg ha^{-1}	Total dry matter kg ha^{-1}	Total uptake of nutrients kg ha^{-1}				g ha^{-1}	
			N	P	K	S	B	Zn
Maize 2002								
Farmer inputs (FI)	2730	6200	59.5	15.0	45.2	4.5	16.4	111.8
FI + SBZn	4560	8850	86.4	20.8	57.1	7.0	19.2	191.8
LSD (0.05)	419	633	8.8	4.1	5.7	0.7	3.8	25.4
2003								
FI	2790	6370	48.3	10.6	39.0	4.4	8.7	113.1
FI + SBZn	4130	9040	73.9	15.7	47.2	6.9	17.1	228.1
FI + SBZn + NP	4880	10377	108.1	19.1	55.6	9.3	19.4	266.7
LSD (0.05)	271	580	8.4	1.6	6.3	0.7	3.6	41.0
2004								
FI	2430	5820	60.0	12.8	59.9	5.3	19.0	89.6
FI + SBZn	3110	7060	69.4	12.9	63.9	5.7	23.6	165.1
FI + SBZn + NP	4230	9470	93.0	17.8	85.8	9.0	42.1	191.9
LSD (0.05)	417	1054	13.4	2.9	13.9	1.3	7.8	38.3
Castor 2002								
Farmer inputs FI	590	1400	23.2	3.1	22.1	2.2	18.1	40.0
FI + SBZn	890	2070	34.2	5.1	30.3	3.6	26.5	62.2
LSD (0.05)	143	360	6.9	1.4	6.6	0.7	4.9	14.2
2003								
FI	690	1610	27.5	6.3	14.4	2.6	11.3	47.8
FI + SBZn	1000	2270	37.9	7.6	24.3	3.9	15.7	70.4
FI + SBZn + NP	1190	2770	46.4	7.5	26.6	4.7	22.2	79.4
LSD (0.05)	186	403	8.0	1.4	6.4	0.8	4.6	13.7
2004								
FI	990	2220	33.8	5.3	31.7	2.4	18.1	41.0
FI + SBZn	1240	2710	54.2	7.4	32.1	3.8	23.3	73.0
FI + SBZn + NP	1370	3350	54.4	7.7	38.9	4.3	30.6	86.6
LSD (0.05)	285	484	13.0	2.2	13.2	0.9	4.2	18.2

Results on yield and nutrient uptake responses of the maize crop clearly demonstrate the importance of alleviating S, B, and Zn deficiencies for increasing the yields of crops such as maize.

Castor

Unlike the maize crop, which is about 100 to 110 d duration, the castor crop takes abut 170 to 180 d for maturity. Secondly, castor pods are used for oil extraction. The oil finds industrial uses. The numbers of farmers who evaluated castor as the test crop in on-farm trials were 8, 17, and 6 in the 2002, 2003, and 2004 seasons, respectively.

The application of nutrient combinations (SBZn or SBZn + NP) over the FI treatment significantly increased pod and total biomass of the castor crop in all the three seasons of evaluation (Table 2).

Compared to FI treatment, FI + SBZn produced 300, 310, and 250 kg ha^{-1} more pods during 2002, 2003, and 2004 seasons, respectively. Nutrient treatment FI + SBZn + NP produced 190 and 130 kg ha^{-1} more pods than FI + SBZn treatment in 2003 and 2004 seasons, respectively. In the 2004 season, castor produced more pod yield in FI + SBZn + NP than other treatments. The stalk and biomass yield also responded to applied SBZn and SBZn + NP as compared to the FI treatment during 2002-2004 (Table 2).

In the 2002 season, the application of SBZn compared to the FI treatment, significantly ($p < 0.05$) increased total uptake of N, P, K, S, B and Zn in the crop biomass at harvest. In 2003, FI + SBZn and FI + SBZn + NP treatments significantly increased the uptake of major nutrients, and S, B and Zn; and also the differences in total uptake of various nutrients under FI + SBZn and FI + SBZn + NP treatments were significant. Similarly in the 2004 season, the application of SBZn and SBZn + NP compared to FI treatment significantly increased the total uptake of N, P, S, B and Zn in the crop biomass, although the differences in nutrient uptake between FI + SBZn and FI + SBZn + NP treatments were not significant (Table 2).

There have been few studies on the response of castor to applied nutrients under dryland agriculture. However, results show that the castor crop responded to the application of nutrients, which were deficient. Clearly, balanced nutrition of the crop can help in increasing the yield of the castor crop.

Groundnut

Groundnut pod and biomass yields were significantly ($p < 0.05$) increased by the application of various nutrient treatments (FI + SBZn and FI + SBZn + NP) as compared to the FI treatment; highest responses were obtained in the SBZn + NP treatment in all the three seasons (Table 3).

Percentage increase in pod yields due to the application of SBZn over the FI treatment were 33, 48, and 29 during 2002, 2003 and 2004, respectively. In the 2003 and 2004 cropping seasons, the treatment FI + SBZn + NP produced 79% and 39% more pod yields than the FI treatment. The groundnut haulm and biomass yields were also significantly ($P < 0.05$) increased by FI + SBZn and FI + SBZn + NP treatments. The increases in pod yields were 240, 250, and 270 kg ha^{-1} due to application of SBZn over the FI treatment during 2002, 2003, and 2004, respectively. In the 2003 and 2004 seasons, 420 and 360 kg ha^{-1} more pod yields were obtained due to the application of SBZn + NP treatment over the FI treatment.

Table 3
Yield and nutrient uptake of groundnut and mung bean in response to fertilization in Andhra Pradesh, India, 2002–2004

			Total uptake of nutrients					
	Grain yield	Total dry matter	kg ha^{-1}				g ha^{-1}	
Treatment	kg ha^{-1}	kg ha^{-1}	N	P	K	S	B	Zn
Groundnut 2002								
Farmer inputs (FI)	700	2690	74.9	7.3	29.3	4.4	40.1	50.2
FI + SBZn	940	3420	95.1	11.3	41.9	6.4	52.1	80.9
LSD (0.05)	103	145	4.1	2.4	3.7	0.7	3.1	5.1
2003								
FI	560	2920	57.7	6.6	27.5	3.7	38.6	59.0
FI + SBZn	810	4150	86.3	7.2	38.1	5.5	56.8	151.5
FI + SBZn + NP	980	4740	114.9	10.6	39.5	6.5	68.4	116.8
LSD (0.05)	59	183	5.6	1.2	3.6	0.5	3.9	13.2
2004								
FI	920	4080	107.8	9.2	47.6	6.8	78.9	87.3
FI + SBZn	1190	4930	124.1	10.8	56.9	6.3	65.1	141.5
FI + SBZn + NP	1280	5060	139.4	15.4	60.9	7.0	106.8	129.6
LSD (0.05)	96	262	8.4	2.3	6.3	0.7	7.6	52.0
Mung bean 2002								
Farmer inputs FI	770	1500	36.7	4.6	25.4	2.3	20.4	45.6
FI + SBZn	1110	2110	53.3	7.4	36.3	4.0	30.4	69.6
LSD (0.05)	145	280	8.2	1.0	5.5	0.4	5.6	5.6
2003								
FI	900	2900	54.7	6.9	52.1	3.0	37.6	59.8
FI + SBZn	1390	4840	87.9	13.7	80.4	7.8	73.0	129.2
FI + SBZn + NP	1540	5420	103.9	13.2	95.3	6.4	79.9	208.4
LSD (0.05)	160	417	14.2	2.1	16.6	1.0	9.4	23.8
2004								
FI	740	2800	59.6	9.0	57.7	3.1	40.2	53.5
FI + SBZn	920	3200	58.7	8.0	55.3	4.8	66.6	69.1
FI + SBZn + NP	1160	4050	71.6	9.0	66.7	5.7	77.8	79.7
LSD (0.05)	131	580	17.4	2.2	11.8	1.1	15.0	16.8

In the 2002 cropping season, the application of SBZn over the FI treatment significantly increased uptake of N, P, K, S, B, and Zn by the groundnut crop. In the second cropping season (2003), the application of FI + SBZn and FI + SBZn + NP over the FI treatment significantly increased the uptake of N, P, K, S, B and Zn; and the differences in nutrient uptake between FI + SBZn and FI + SBZn + NP treatments were significant for N, S, B and Zn (Table 3). Similarly, in the 2004 season the application of nutrient treatments over the FI treatment significantly increased the uptake of N, P, S, B, and Zn in the biomass.

The highest nutrient uptakes were obtained in the FI + SBZn + NP treatment and the uptake was significantly greater for N, P, S, and B than those in the FI + SBZn treatment (Table 3).

Groundnut yields are low in rainfed conditions, especially if the crop is affected by terminal (during pod formation) drought. Nevertheless, results suggest that balanced nutrition of the crop even under rainfed conditions can increase and stabilize the groundnut yields. The highest groundnut pod yields were achieved when the applications of SBZn and NP were made together.

Mung Bean

Mung bean is a relatively short duration crop, of about 70 d duration. Being a legume, mung bean is grown on marginal soils with very little external inputs of nutrients. Farmers used mung bean as the test crop in 9 trials in 2002, 6 trials in 2003 and 12 trials in the 2004 cropping season.

During the three seasons' evaluation, the grain and total biomass yields of the mung bean crop were significantly ($p<0.05$) increased due to the application of various nutrient combinations (FI + SBZn and FI + SBZn + NP) as compared to the FI treatment (Table 3).

The grain yield responses to the application of FI + SBZn treatment were 43, 54 and 24% larger compared to those in the FI treatment during 2002, 2003, and 2004, respectively; and the haulm yield responses for these seasons were respectively 38, 72, and 10% larger than in the FI treatment. In the 2004 season, FI + SBZn treatment gave 180 kg ha^{-1} more grain yield than the FI treatment, while 420 kg ha^{-1} extra grain yield was obtained in the FI + SBZn + NP treatment compared to the FI treatment (Table 3).

In the first year (2002), the application of SBZn to FI significantly increased the total uptake of N, P, K, S, B, and Zn in the mung bean crop biomass. In the 2003 cropping season, the application of SBZn and SBZn + NP to the FI treatment significantly increased the uptake of nutrients, although the differences between FI + SBZn and FI + SBZn + NP treatments were significant only for N and Zn uptake. Similar results on the total uptake of nutrients by the mung bean crop biomass were obtained in the 2004 cropping season (Table 3).

As in the case of maize, castor and groundnut crops in this study, the mung bean crop also responded to the applications of S, B, and Zn, as indicated by significant increases in grain and total biomass yield and the uptake of major nutrients and S, B and Zn in the crop biomass.

CONCLUSIONS

The deficiencies of N and P are well known in soils of the SAT regions in India. More importantly, results demonstrate widespread deficiencies of S, B and Zn in the SAT soils and hence the observed response of crops to the application of these nutrients.

Results showed that responses of crops to the application of S, B, and Zn varied across crops and with the application of N and P; the crop yield and nutrient uptake responses clearly are significant and seem of similar magnitude to those reported for field crops under irrigated agriculture (Takkar, 1996; Scherer, 2001; Fageria, Baligar, and Clark, 2002; Katyal and Rattan, 2003). Clearly, the deficiencies of S, B, and Zn assume critical importance for increasing and sustaining crop productivity of the rainfed cropping systems in the Indian SAT.

Results from three years of on-farm study clearly demonstrate that under dryland conditions the applications of S, B, and Zn is essential to increase productivity of crops such as maize, castor, groundnut, and mung bean. The best results are achieved when the applications of S, B, and Zn are combined with the application of N + P. Also equally importantly, soil testing was found effective to diagnose and predict the deficiencies of S, B, and Zn in farmers' fields in the semi-arid zone of India. Results showed that for sustained increase in productivity, the drylands need applications not only of major nutrients such as N and P, but also of nutrients such as S, B, and Zn.

ACKNOWLEDGMENTS

We thank Andhra Pradesh Rural Livelihood Program (APRLP), Government of Andhra Pradesh and Department for International Development (DFID), UK for financial support. We are also thankful to Mr. S P Tucker, Project Coordinator and Ms T K Sreedevi, Additional Project Coordinator APRLP for their assistance in implementation of the watershed program under which the nutrient management trials were conducted.

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